History of Medical Informatics at Utah

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This has been a very special experience for me to attend this conference, meet people that I haven't seen for a long time, and reflect on our associations over the past years.

My goal today is to "minimize your grief" in the terms used by our last speaker by trying to keep it as light as possible and at the same time convey some of the feel for the environment in which the developments that we've worked on have evolved.

In order to do that, I'm going to keep it sort of personal and hope this will be of some interest to you and not be offensive.

My background is cardiology, and I came to Latter Day Saints (LDS) Hospital, which is a 525-bed, tertiary-care, private hospital with a university affiliation in Salt Lake City, in 1954. At that time, I had learned how to do a heart catheterization. There was one surgeon at LDS Hospital who was already in this business, and I came there to set up a catheterization laboratory.

The first year we managed to get a diagnostic facility running, and, fortunately, about a year later the hospital got a sum of money from the Ford Foundation. Apparently, it was a grant given to most private hospitals across the country to use for something other than direct patient care activities which already existed.

Well, with that kind of constraint, it wasn't too hard to talk the hospital administrator into establishing a research department. So with that, we built our little cath lab, one floor up in a one-room research laboratory, and on top of that a room for some dogs, and we began doing some research.

The first project that I was interested in involved trying to understand how a pressure wave gets distorted as it travels from the aorta down to the radial artery. Well, I'd done a thesis back in Minnesota on a method for calculating stroke volume from the shape of aortic pressure wave. One of the assumptions we made in that work was that the pressure wave didn't get distorted as it traveled down the artery. We made that assumption only because we didn't know how to handle the distortion. It was an interesting question to me.

At the time I was taking a course at the university to learn something more about mathematics. I didn't know very much, and in this course the instructor introduced me to the notion of Fourier analysis—transforming information into another domain. I think that is what informatics is all about isn't it?—rearranging information to give one additional insights. I was fascinated by this, and I bought myself a long slide rule, which I still have, with trigonometric functions on it. I remember spending a whole day analyzing a single aortic pressure wave into its Fourier components. Well, the next day the instructor talked about another concept, which was the notion of a transfer function. If you know the Fourier components of the upstream pressure or the input to a system, and you also know the output in terms of its frequency components, then you can develop in terms of just ratios some notion about what's happening to each of those harmonics as it traverses the system.

Of course, I analyzed in the same heartbeat, then the downstream wave form and plotted the ratio of these—it peaked. It looked like a resonant system. Well, the instructor was talking about systems that did this kind of thing, and one of the systems that will do this is a resonant circuit, an RLC circuit. So, I thought it might be interesting to build such a circuit with variable components so that we could feed the signal from the pressure transducer measuring upstream pressure wave form into the resonant circuit and then tune the circuit by varying the values of R, L, and C until the downstream wave form matched the circuit output. So we did that. We built that kind of a circuit with big capacitor, inductor, and resistor and set it up in this little laboratory above the cath lab. With a patient on the table for some kind of diagnostic procedure and a catheter in the aorta and another one down in the radial artery, I'd let my assistant talk to the patient while I ran upstairs and started "twiddling the knobs." I would adjust the system until the downstream wave from from the artery overlapped the downstream wave form from the RLC circuit. At that point, we could read the settings for the components of the circuit that represented the electrical analogs of the resonant properties of the arterial bed between the two recording sites. This was our first analog computer and the thrill of building a model and testing its performance against a real biological system is still the motivation for much of our work in medical informatics. It got me excited about it.

We published a paper as a result of studying some 80 patients, which demonstrated that the resonant frequency of the aorta increases with age. This isn't too surprising, but for the first time we had a method for actually getting a quantitative feel of a physical phenomenon that we couldn't measure directly. In fact, I remember talking to Allen Toronto, who was the resident working with me at the time and later worked for many years with me, that maybe we shouldn't publish this quite yet, "It's so exciting that we ought to explore this tool a little bit before we tell the rest of the world about it." You've got to realize that we're living at LDS Hospital out there in Salt Lake City in a sort of isolation, and we thought that we had the world by the tail. But anyway, we went ahead and published of course. As a result, we got our first NIH grant.

That first grant was a real break for us, because now we could really justify spending some time in research. We began studying all kinds of systems using this sort of approach.

We looked at the same kind of transfer function using indicator dilution curves. By recording an upstream curve and a downstream curve and deriving a transfer function, one had a measure of the distribution of their transit times across any segment of the vascular bed. We built models of control mechanisms in the circulation using this approach. We looked at the carotid sinus for instance. We measured its transfer function using for input the carotid artery pressure and for output the frequency of action potentials recorded from a single fiber of the carotid sinus. It was an exciting period.

This was 1956. After a few years of exploring this tool, I learned that the university had acquired a digital computer. This sounded like a very interesting device, but I needed some kind of excuse to spend time learning how to use it. By that time, I was trying to support a family by running a diagnostic cardiovascular laboratory, and I couldn't just run off and play with a computer. I read an article in *Science* by Ledley and Lusted that suggested using a conditional probability approach to modeling the way a physician thinks. At the time, we had lots of patients coming through our laboratory who had congenital heart disease, and we began systematically collecting data on the incidence of history and physical findings that were obtained before catheterization revealed the ultimate diagnosis. We accumulated a data matrix by asking each physician who referred a case for study to fill out a checklist as to what the manifestations were. After we had enough data to get some statistical estimates, we compared the computer diagnosis using Bayes's theorem to what the physicians thought the diagnosis was before they sent the case in. The computer outperformed all but one of the physicians, most of whom only occasionally saw a patient with congenital heart disease.

We reported this work at the American Heart Meeting in 1961 and it was an interesting experience. Some of the senior cardiologists in the country were there. A number of them got up and expressed how upset they were about the very suggestion that a computer could do anything quite as subtle as suggesting a diagnosis to a clinician.

That was a very positive experience for me, and much of our subsequent thinking has been based on our optimism about the fact that indeed the computer does have this kind of capability if we're just clever enough to devise ways to take advantage of it.

We published that study, and again that was helpful in getting our first grant for a digital computer. So, we began to find ways to use that digital computer, and of course the first thing we applied it to was the heart catheterization lab because that was an environment that I had some control over. We interfaced the various instruments that we used—the pressure transducer, the oximeters, the ECG signal—directly to the computer. That was not a trivial job in those days. That was the early days of analog–digital converters.

I was very intrigued by some of the comments that Dr. Caceres and Dr. Pipenberger made this morning about analog signals, because we were going through the same kind of experience in learning to perform pattern recognition. We were able to get a program for the cath lab up and going, and it did have a significant impact on the efficiency of performing a diagnostic procedure in the laboratory. Before the program was in use, it required as much time to manipulate the catheter into the various locations in the patient's heart and record measurements as it did to analyze that long scroll of paper, calibrate the recorded wave forms, and generate a report. The program generated the report by the time the last measurements had been recorded.

So, we thought after doing the cardiovascular lab, "Why can't we do that in some of these other areas?" About 1968, we moved into the operating room. These were the early days of open heart surgery, and we had the responsibility of doing the monitoring during surgery on these patients. Our first systems allowed the anesthesiologist to record in the computer all his or her observations and procedures and control the sampling by physiological transducers of signals directly from the patient. We developed methods for inserting small-diameter arterial catheters the night before surgery percutaneously through a thin wall of 18-gauge needle into the radial artery, and we trained nurses to do this in order to make the procedure cost effective. The nurses learned how to put those arterial catheters in very efficiently. When the patient came up to surgery the next morning, all the anesthesiologist had to do was connect and calibrate the pressure gauge, and he was on his way. When this was working well, we moved into the intensive care ward. We wanted to provide a continuity of the patient's record and much the same kind of activities occur in the ICU, at least in the post-op ICU, that take place in the operating room. It is essential for patient care that an accurate and current record of blood, other fluids, and medications given the patient be recorded and made available as the patient is moved to the intensive care unit from the operating room.

Reed Gardner has been the man in our department primarily responsible for patient monitoring activity. Reed had the foresight to see that this activity could be spread to the rest of hospital. These same monitoring principles, where one samples information at specified intervals or on demand and provides immediate access to the information in a convenient form, could be applied to other areas of the hospital as well.

When Reed first came to our group, we were already a department of the University of Utah. The department was established 22 years ago as the Department of Biophysics and Bioengineering in the School of Engineering although we were physically off-campus at the LDS Hospital. Reed came to us with a degree in electrical engineering and earned a PhD in our department. He has taken the responsibility not only for the monitoring activities, but for many other interesting aspects of the system that I'll be describing to you.

I think our success, if we have had any, has been our ability to get and keep good, bright people that have come along. And Reed typifies these; in fact he was the first of these to join our faculty.

In patient monitoring, our focus initially was largely on collecting information and devising displays to present the data in some transformed way, either a graphics or tabular report. We tried a variety of ways to display information to physicians that would make it useful, and we finally came full cycle. We found ourselves after several years coming back to some of the original tabular methods. We pretty well explored methods for data display, and I discuss some of the ramifications of this later in this paper.

I was asked to join the computer study section, and I met Bruce Waxman. That experience had a major impact in my professional life, and I want to say a few words about him. I consider Bruce to be the "Oliver North" of the medical informatics field. I mean, he found a way to get things done. If he believed in something, he made it happen, and it didn't really matter what kind of gyrations he had to go through. We've already heard about the LINC experience. Bruce took our patient monitoring system, which was beginning to blossom in the ICU, and managed to find funds to plant copies of it at Massachusetts General Hospital and at George Washington University. It didn't survive very well in either place. Bruce put computers in doctors' offices all the way from Boston down to Washington. I remember he tried to put our Bayesian history-taking program in this system, but it was written in MUMPS, which couldn't handle all the computation required.

Bruce really is responsible for initiating what was called the Information Exchange Group. At the time, there were already one or two of these groups established in biochemistry and some other areas where NIH had established a system for exchanging information among people in a very active research area. Bruce asked me to start one of these in medical computing, and I did. The rules of the game were that anyone could belong to the group if they submitted at least one paper. Once you submitted a manuscript (and you had to submit the paper before you submitted it to any journal), NIH guaranteed that the paper would be distributed to everybody else in the group within two weeks. There was no editing done to it at all. The author sent it to me, I sent it to NIH, they'd publish it and distribute it to the people in the group. It was great. I mean we had a great communication link going, but it only lasted for a couple of years because several of the journals didn't like it, and they began saying, "If a manuscript was circulated this way, we won't publish it."

But out of this experience grew the beginnings of the journal *Computers and Biomedical Research*. Bruce asked me to negotiate with Academic Press about starting a journal, and I got together many of leaders in the field—some whom I have worked with since 1968 are in this room. We had only one meeting of the editorial board in the Chicago airport. We met there during the day and flew home that night. That's the only meeting we've had as a group, but we've had a lot of good correspondence over the years—back and forth and sharing information about specific manuscripts. It's been a wonderful experience for me, and I thank you, Bruce, for initiating all that.

Now, the next subject we tackled in our laboratory was also in the area of signal processing. A fellow by the name of Allan Pryor came into our program. Al had a background in mathematics and came with us to pursue a PhD. For his thesis, he developed a system for classifying ECG signals. He took an approach using three orthogonal leads even though this isn't the approach physicians use. He was able to generate all of the other leads synthetically for display to physicians. This ECG program was put in operation at the LDS Hospital in 1969 and has been in continual use until just this year when it was replaced by interfacing a commercially available ECG analysis program to the HELP system.

We implemented that ECG system by using a cart that could be wheeled into any patient room in the hospital. Using the phone line in the room and the modem on the cart as the input channel, the computer output was displayed on a memory oscilloscope, which had a TV camera focused on it that then would broadcast on Channel 13 to all patient rooms. I remember on one occasion, Jack Whitehead of Technicon was in the hospital following a skiing accident in Salt Lake, and he happened to tune to Channel 13 as he lay in his bed. He saw these messages about ECGs and asked the nurse what it was all about. As a result, I had the chance to go down and meet him.

Al has provided to our department not only mathematical and statistical expertise, but computer know-how. He is really the professional "computenik" in our group. Most of us had never had a course in computer science; there weren't such things in those days. But Al had some experience with NASA before coming to Utah, and that proved to be very valuable for us. Pryor has provided the system's know-how over these years that has resulted in a decision and database system that really works in a clinical environment.

This was about the time we began working to interface the clinical lab with the computer. It was apparent that if we were really going to serve the information needs in the ICU, we had to have information from other sources as well. John Morgan, one of our students, devised the first interface to the laboratory for us—not the first in the world, I'm sure, but it was a first for us. He interfaced a number of the analog laboratory instruments and developed a system that allowed the computer to sample those signals directly. We had a Control Data 3300 in those days that used to do everything. We built our own time-sharing system, and all the applications programs were written in assembly language.

That system was used to sample all the ECG monitoring beds (200 samples a second) while it was sampling the laboratory data, the pressure signals from different areas around the hospital, as well as interfacing with all the terminals. Each user had 2000 (24-bit) words of memory to work with and had to control his own overlays. It was not the most efficient system to program, but it hummed like a top. We used that computer system for 18 years.

John Morgan joined our faculty after graduating but didn't really like the academic environment. He preferred to write programs rather than manuscripts. He left the university and with his own initiative and resources developed a company called Code 3 to automate the coding of discharge diagnoses. He recently sold that company to 3M for $16 million, a nice success story. He gave a grant of $100,000 to the department to establish a fellowship.

We started developing a self-administered history—largely the result of Tony Gorry and Octo Barnett's work on sequential Bayesian decision making. We developed a sequential Bayesian history that we implemented as part of a screening program for elective surgical patients. I had been on site visits to Morris Collen and knew about his work in screening. Our implementation included ocular tension measurement, ECG measurements, spirometry on every patient that was coming in for elective surgery, this history program, and a battery of laboratory tests. The screening was designed to pick up secondary problems. The patient's primary problem was known, since he or she was being admitted for elective surgery. This program has served us well over the years. We've done over 35,000 sequential Bayesian self-administered patient histories. Patients react very well to it, and it's been a useful source of information for the surgeon. Incidentally, in 70% of patients, the primary diagnosis can be made from history alone.

One day I was down in the ICU looking at one of the displays on the computer terminal. We had, at that time, a display with a red, yellow, and green light for each patient. When the red light was on, some emergency had occurred. The nurse had to press the light (interrupt button) to see what had caused it to go on. The yellow light was used to indicate that a trend had occurred. For this patient, there was a yellow light on, and the nurse was over at the bed pumping up a blood pressure cuff and on the other arm was an arterial catheter recording the pressure. I waited until she got through and I said, "Why are you doing that?" It turned out that she was simply frustrated. We were overloading her with information, and she didn't know what to make of it. We were asking her to do something she hadn't really been trained to do. It was really this experience that moved us into thinking, "We need to do something more than just display data; we need to help the nurse with the decision making." In this case, it turned out that the patient was having a cardiac tamponade. We went through a half-hour or so of reviewing information with the resident before coming to that conclusion, and I thought, "Why don't we build a program that would allow us to preserve that logic that we've just been through so the next time this kind of situation occurs, the system will recognize it?" It was from this experience that the decision support components of the HELP system evolved.

The HELP system is built around a central patient database that interfaces to a dictionary and to a knowledge base. The knowledge frame is driven by the data as it is acquired. The dictionary has pointers from each item to the frame using that item. Execution of a frame may result in a decision that can then be fed back to various places in the system. The knowledge base is built on the assumption that we want to not only provide consultation, but we want also to provide alerts. That is, we want to provide help for people that may not know they need help. Some of the mistakes made in patient care are the result of not knowing. They are just oversights. A lot of our effort has gone toward recognizing the latter type of errors. One of the most successful is a system for alarming at the time the prescription is written on a potential adverse drug reaction.

Paul Clayton developed a clever system for ordering radiology procedures. At the time an x-ray procedure is ordered, frames representing all the possible interpretations of that procedure are processed. Each frame is associated with a certain set of clinical manifestations. For example, if a chest film is ordered, there is a 30% chance that it will be normal. But if that patient is coming from a post-op ICU ward, is running a fever, and has an elevated white blood count, the chances are much more likely that the interpretation will be pneumonia. So at the time the procedure is ordered, this "expert system" generates a requisition that has on it the five most likely interpretations based on the relevant clinical findings in the patient's database.

We developed many of these kind of applications. When the regional medical program came along, we jumped on the band wagon and over a weekend wrote a grant that got us a second computer that helped us get into a position to support clinical applications 24 hours a day in a real clinical setting. We used one machine for development and one machine for providing service.

After 18 years with the CDC 3300 computer, we began thinking how we were going to get funds to move the HELP system to another piece of equipment. We explored possible relationships with the Navy, with NIH of course, and with Health Services Research. Nobody wanted to support a reprogramming effort; that's not research. We finally went to our hospital administration. The hospital, which had already committed to each one of these applications as the research phase ended, now was asked to make a decision, "If you want these computer-based services we've been providing, are you willing to pay for a new machine and the reprogramming effort?" The medical staff and administration made that commitment, and so LDS Hospital funded reprogramming HELP on a Tandem computer. This is an example of the friendly, supportive environment in which we have worked.

Over the 22 years since our department was established as an academic unit of the University of Utah, its name has changed a number of times. After 10 years as "Biophysics and Bioengineering" in the College of Engineering, we moved to the School of Medicine as the "Department of Medical Biophysics and Computing" and three years ago changed the name to "Medical Informatics." We have 13 full-time faculty and about the same number of auxiliary appointments of people in other departments. We feel it's very important that Medical Informatics be involved with every department. We look to these departments for real problems to solve. Last year there were 54 graduate students in the program, and there seem to be plenty of opportunities for them when they graduate. Often in these years, I've wondered if informatics is just a passing phenomenon, and after we solve today's problems it will go away. I don't think so. I think we're into a discipline that is going to stand on its own feet, that we have challenging things ahead of us to solve and that medical informatics represents a major new direction for medicine.

Finally, there have been some spin-offs into industry that I think are significant. Because the Dean wanted some material to go to the legislature and prove that we are doing something for the economy of the state, Reed Gardner collected a list of some of the companies that have taken advantage of the technology spun off from our department. Reed estimated that the annual payroll from these companies amounts to approximately $90 million a year just in the state of Utah.

I have been fortunate in having bright and enthusiastic companions to work with and a supportive environment both on the local and national scene. We have all participated in the blossoming of a new discipline whose domain touches the intellectual core of medicine and at the same time provides opportunities for immediate solutions to practical problems. And I have a feeling that we have only scratched the surface of this exciting new field.